Energy Management of Air Conditioning System when Facing Low Cooling Load

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Abstract

The Main Hall Building (MHB) at Shinawatra University was designed with the purpose of energy conservation in a tropical zone. However, energy consumption in this building is relatively high when considering the limited number of occupants and the efficiency of the air conditioning system. This study aims to audit the energy consumption of the air conditioning system in order to determine its energy performance, and to identify an efficient way of managing the system. Recommendations for the energy conservation of the air conditioning system are proposed, and the energy cost savings related to the recommended schemes are determined.

The air conditioning system takes the highest share of energy consumption at approximately 70%. The rest is consumed by lighting and other systems at 12% and 18%, respectively. It was found that the chiller plant is operating inefficiently, because the central air conditioning system was not designed to operate at low cooling load demand. Energy conservation using the existing air conditioning system can be achieved by changing to the smaller (190-ton) chiller during office hours. Many air conditioned areas in the MHB, which are not fully utilized, should be closed down to decrease the load of the chiller and reduce the energy use of the air handling units (AHUs) and fan coil units (FCUs). A multiple pump operation in the chiller plant system is also recommended.

By following the recommended management schemes for an air conditioning system, the university can save approximately 2.26 million baht annually. This finding illustrates the importance of good energy management in buildings.

Keywords: Energy Management; Energy index; Energy Cost Saving; Energy Saving; Main Hall Building; Shinawatra University

1. Introduction

Nowadays, the high price of fuel has made a great impact on every sector of Thailand. After the enforcement of the Royal Decree on Designated Buildings in 1995 [1], building designers must be concerned with not only the construction cost, but also the efficiencies and the cost of energy consumption of buildings.

The Main Hall Building (MHB) was specifically designed for the purpose of energy conservation in a tropical zone and is considered one of the best buildings in Thailand, in this area. Its energy consumption per total usage area is extremely low. However, energy use in this building is relatively high when considering the limited number of users and the efficiency of the building systems, especially during the summer semester, when the number of staff and students is less than 200. The building was designed to operate with maximum efficiency when it is occupied by 500 people or more. Since the air conditioning system of the MHB consumes more energy than any other building systems combined, various recommendations for the energy management of this system are proposed together with the estimated energy cost savings in order to improve the energy performance of the MHB.

2. Background

Because of appropriate design and systems integration, the required size of a central air conditioning system for Shinawatra University is 3,500 tons smaller than for a regular building with the same total floor area. Its size is only 30% of a typical system used in other buildings. In the MHB, cooling load requirements for classrooms are approximately 45 m^2/ton, while the cooling load for classrooms in a typical academic building is 15 m^2/ton [2].

The integrated components of the air conditioning system at Shinawatra University are briefly described as follows:

- **Water cooled chiller**

The use of district cooling in the chilled water system reduces the size of the chiller system. The required capacity of the chiller system is much lower than that of one in a similar type of building. At the undergraduate campus of Shinawatra University, the chiller plant supplies chilled water to the MHB, laboratory building, dormitory buildings and the skylink as shown in Figure 2.1 [2].

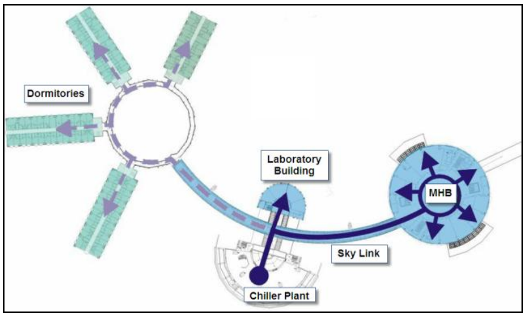

Figure 2.1 Air Conditioning System Service Layout

It consists of two 375-ton centrifugal chillers and two 190-ton screw chillers. The centrifugal chiller is usually operated at the regular load requirement during office hours 8.00 am - 5.30 pm on Monday to Friday. The smaller screw chiller is operated on weekdays during the night and on the weekend when a part load requirement occurs. For both types of chiller, the chillers of the same size are rotated into operation everyday. In the case that one of chillers is accidently shut down; the other chiller will be operated instead.

- **Pond cooling system**

With the design of large pools around campus, the pond cooling system offers great benefits for energy conservation. The chiller system uses the water from the pools as a source of heat sink. Water flows by gravity from the higher pool toward the lower pool with no electricity use. The heat can be released from water by natural evaporation during the flowing time. In comparison with the cooling tower, the pond cooling system uses much less energy, and creates no environmental pollution since it does not increase the temperature and humidity of the environment.

- **Fresh air system**

The fresh air system of MHB has been designed to work separately from the air conditioning system. The separation of the fresh air system allows better control of the fresh air volume. The fresh air from outdoors is treated by the Outdoor Air Treatment unit (OAT) before being delivered to the building. The OAT reduces the temperature and humidity level of fresh air, and supplies suitable amounts of fresh air to the indoor spaces. As a result of the use of OAT, the cooling load demand is reduced.

- **Heat recovery wheel**

The heat recovery wheel works as a heat exchanger to recover the discarded cooling air from the system. The recovered cooling air is used to cool down the new incoming fresh air of the OAT.

- **Heat pipe**

In the air conditioning system, the use of a heat pipe can directly save energy. The benefits of the heat pipe in front of the cooling coil are to precool the air temperature and to remove the moisture from the air. The air coming out from the cooling coil is mostly overcooled, and contains high moisture with low temperature. It requires high energy to reheat and extract the moisture from the air. Thus, the heat pipe at the back of the cooling coil is utilized for reheating air without using additional energy for the dehumidification. The result is an air conditioning system with the ability to remove 50-100% more moisture than regular systems [3].

3. Methodology

The total energy consumption of air conditioning system is represented by the following Equation (1).

$$E_T = [\sum (W_{Ai} \times t_{Ai}) + U_{ch} + U_p + U_{other}] \quad (1)$$

where

E_T Total energy consumption of air conditioning systm

W_{Ai} Work load of AHU i or FCU i

t_{Ai} Using time of AHU i or Fan coil i

U_{ch} Energy use of chiller for MHB

U_P Energy use of pump in chiller system

U_{other} Energy Use of other equipment

The energy consumption of the air conditioning system consists of the energy uses of the chillers, air handling units (AHUs) and fan coil units (FCUs), fresh air, pumps, and other equipment.

Based on the results of the energy audit, the most suitable energy conservation schemes for the air conditioning system of the MHB are proposed in order to increase the efficiency of the system. The proposed schemes emphasize on the management of system operation, time schedules, and user behavior.

4. Results

As shown in Figure 4.1, the air conditioning system takes the largest share of energy consumption at 70% of the total, followed by other systems and the lighting system at 18% and 12%, respectively. The energy consumption in the air conditioning system is significantly higher than any other system. Its annual energy consumption is equal to 618,410 kWh, which costs over 2.01 million baht based on the average electricity rate of 3.26 baht/kWh between year 2005 and 2006 [4].

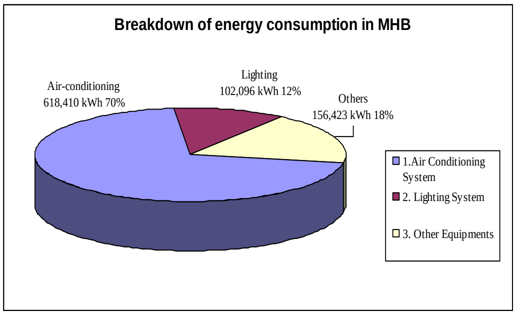

Figure 4.1 Breakdown of Annual Energy Con-sumption in MHB

The major share of the electrical consumption in this system is from the chillers at 74%. It follows by the energy uses of the AHUs and FCUs, and chiller pumps at 16% and 7%, respectively, as shown in Figure 4.2.

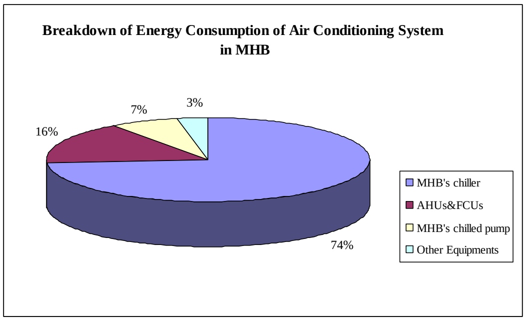

Figure 4.2 Breakdown of Energy Consumption of Air Conditioning System in MHB

4.1 Energy use of chillers.

The chiller system consumes over 70% of the total electricity use of the air conditioning system. The energy audit was carried out on the chiller system. The power demand of each chiller was continuously measured for 5 days from August 28 to September 7, 2006.

The daily average power demand of the 375-ton chiller is approximately 268 kW with the average peak power demand of 295 kW occurring between 8.00 and 9.00 am. The power demand of the 190-ton chiller is typically less than half of the 375-ton chiller. Its daily power demand ranges between 80 to 90 kW.

The ratio of the energy input and produced cooling load (kW/ton) can be used to express the efficiency of each chiller. It represents the amount of electrical power used to produce 1 cooling ton. The power demand and produced cooling load of the chiller can be used to estimate the performance of the air conditioning system (kW/ton). These data have been plotted in Figure 4.3 and 4.4, and are compared with the chiller manufacturer's specifications. The actual efficiency data of 375-ton and 190-ton chillers in these figures were fitted into the average efficiency curve at the different capacity levels.

In a comparison between the actual performance and the manufacturer's designed values, the efficiency of the 375-ton centrifugal chiller is relatively poor. When the chiller runs at less than 55% of its capacity, the plotted data tends to shift up and further away from the designed values, which show more power consumption and lower performance. However, when the chiller operated at 55-70% of its capacity, the plotted data tends to get closer to an specification value line, which shows an increase in efficiency of the chiller. The 375-ton chiller seems to operate inefficiently, since the average cooling demand is about the 55-70% of its capacity.

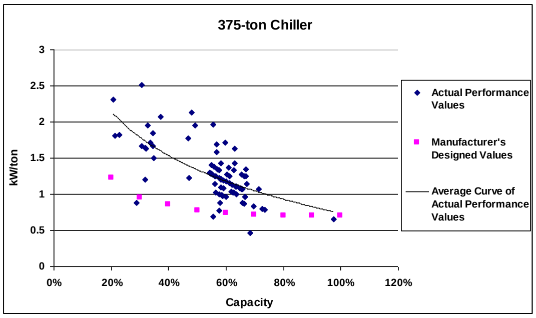

Figure 4.3 Efficiency of 375-ton Chiller

The actual efficiency of the 190-ton chiller in Figure 4.4 is relatively close to the designed value when the chiller runs at between 60-100% of capacity. The chiller is able to operate at high efficiency when it runs at these percentages. However, the chiller is frequently operated at a low capacity (30-60% capacity) due to the small cooling load demand, resulting in more power consumption and lower performance

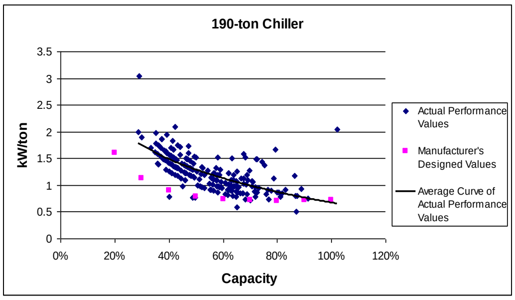

Figure 4.4 Efficiency of 190-ton Chiller

4.2 Energy use of AHUs and FCUs

The monthly energy consumption of AHUs and FCUs was about 16% of the total energy consumption of the air conditioning system.

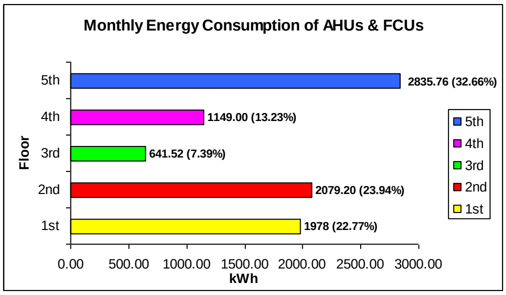

Figure 4.5 Monthly Energy Consumption of AHUs & FCUs

The fifth floor, which is occupied by a library, faculty offices and a studio, consumed the highest amount of energy at about 2,835 kWh or 32%, as demonstrated in Figure 4.5. It is followed by the energy consumption of the second and first floors at 2,079 and 1,978 kWh, respectively. The AHUS and FCUs on the third floor consume the minimum amount of energy at 641 kWh.

4.3 Energy use of chiller pumps.

In the chiller system, there are 4 primary pumps connecting separately to 4 chillers, and 3 variable speed drive (VSD) secondary pumps. The primary pump works constantly when its connected chiller is operated while the secondary pump is operated according to the cooling load demand of air-conditioned areas. The energy consumption of the primary pump is already included in the energy consumption of the chiller as it uses the same electricity meter, whereas the energy consumption of the secondary pump is measured separately.

The energy use of the secondary pumps is only 7% of the total energy consumption of the air conditioning system. The annual energy use of the chiller pumps for the MHB was 41,149 kWh during August 2005 and July 2006.

5. Analysis

The energy consumption per total usage area of MHB (21,810 m^2) is 40.21 kWh/m^2, which is remarkably low when compared to other typical buildings with similar usable area [5]. On the other hand, the energy consumption in this building is relatively high in term of energy use per capita due to the minimal number of users, which results in the low cooling load demand. The air conditioning system was not designed for such low cooling load demand, and thus it cannot be operated up to the designed capacity for high efficiency.

Therefore, energy conservation schemes and their energy cost savings are proposed for the management of air conditioning system of the MHB in order to improve its energy performance.

Because the air conditioning system consumes more than two thirds of the total energy consumption of the MHB, reducing the energy consumption of this system is of the most importance and will have the greatest impact on the energy conservation at the MHB.

5.1 Energy conservation for chillers.

The chiller plant consumes the largest amount of energy at about 1,480,535 kWh annually. To reduce the energy use of the chillers, three energy conservation schemes are proposed.

- *Operate the small chiller and increase the temperature of leaving chilled water*

In accordance with the analysis of the chiller, the energy consumption of the chiller plant could be reduced by operating a small chiller during office hours in winter season (December-January) and two semester breaks (April-May and October).

The cooling load demand during the day time in regular semesters only reaches 50-70% of the 375-ton chiller's capacity. This causes the chiller to operate at low efficiency. The annual average cooling demand is about 207 tons of refrigeration, which indicates that there is a possibility of running the small 190-ton chiller during the winter season, because the cooling load demand of the chiller will be considerably lower than the average value during that period. The demand of cooling loads during semester break is also low due to the minimal activities in the MHB.

Another strategy for the reduction of energy consumption of chiller is to increase the temperature of leaving chilled water. The temperature of the leaving chilled water could be increased from normal 7.22ºC or 45ºF to 8.89ºC or 48ºF in order to produce an indoor temperature of 22-25ºC. This indoor temperature level is slightly lower than the recommended thermal comfort temperature for Thailand of 26-28ºC [13].

The experiment was set up and performed between 1st December and 11th January 2007 to estimate the energy reduction of the chiller plant when the small chiller is operated during office hours on weekdays with the leaving chilled water at 48ºF. It was found that energy consumption can be reduced by 37% or 1,463 kWh daily when running the 190-ton chiller, instead of the 375-ton chiller with the higher temperature of the leaving chilled water.

Considering the academic calendar of Shinawatra University, the small chiller could be operated approximately 5 months or 100 days per year during the winter season and two semester breaks. Thus, it is possible to achieve an energy saving of 476,938 baht annually. With this amount of energy cost saving, the university should attempt to operate the small chiller for the whole year.

- *Operate the small chiller during the regular and summer semesters*

The operation of the small chiller during office hours in the regular and summer semesters is another alternative to reduce the energy consumption of the chiller.

However, this alternative would only be possible if the air conditioning system for the dormitories was separated from the central air conditioning system and split-type or another type of air conditioning system was installed instead. The operating schedule of the air conditioning is proposed as shown in Table 5.1.

Table 5.1 Regular and Proposed Operation of the Air Conditioning Systems during the Regular and Summer Semesters

Summer and Regular Semesters		
	Regular operation	**Proposed operation**
Daytime during office hour 8.30 am-5.30 pm	375-ton chiller	190-ton chiller + Split type (Dormitories)
Nighttime 5.30 pm - 8.30 am	190-ton chiller	Split type (Dorm and UPS, PABX, Cafeteria, Control room and etc.)

The collected data of the 375-ton chiller between 26th July and 7th August 2006 was used to calculate the remaining cooling load when shutting down only the dormitory buildings from the central air conditioning system and when both dormitory buildings and the sky link between dormitories and MHB were shut down as shown in Figure 2.1. Under these conditions, the percentage of the small chiller operation in different ranges of chiller capacity is illustrated in Figure 5.1, which indicates how often the chiller is operated at each different range of chiller capacity.

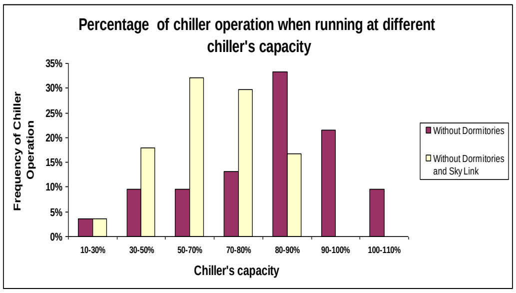

Figure 5.1 Percentage of Chiller Operation when Running at Different Chiller's Capacity

Without the dormitory, 54% of the chiller operation is in the range between 80-100% of the chiller's capacity which allows high efficiency because the chiller operation is almost at its full capacity. On the other hand, to exclude both the skylink and dormitories, the chiller often is operated in the capacity range between 50-80% which may result in lower efficiency.

It is also noted that less than 10% of chiller's operation may exceed the full capacity of the small chiller. If the cooling load demand is higher than the capacity of the 190-ton chiller, the AHUs in the skylink can be turned off to decrease the cooling load demand during that time.

In addition, by separating the dormitories from the central air conditioning system, the installation of a split-type or other air conditioning system is required. However, the central air conditioning system should still be operated at the dormitories whenever it is needed. For instance, the cooling load demand during winter may be very low. Operating only one small chiller for the whole campus including the dormitories may be sufficient. It is recommended to install split type air conditioning systems for use in the library, private automatic branch exchange (PABX), uninterruptible power supply (UPS) and control rooms after office hours.

Implementing the energy conservation scheme for chillers would result in the reduction of the monthly energy consumption by 33,663 kWh. Annually, the total energy saving after excluding the dormitories from the central air conditioning is equal to 235,643 kWh as shown in Table 5.2.

Table 5.2 Total Energy Saving after Excluding Dormitories from Central Air Conditioning System

	Mon	Tue	Wed	Thu (kWh)	Fri	Month
- Energy use of the 190-ton chiller after excluding the dormitories from the central A/C	4,933	6,073	6,130	5,661	4,848	27,645
- Energy use of the chiller's pump						2,673
- Energy use of split-type in dormitories						58,722
- Energy use of split-type in PABX, UPS, Library, Control room and etc.						10,640
- Total estimation of energy cost						99,680
- Actual energy use in July 2006						133,343
- Energy saving per month						33,663
- Energy Saving per year						**235,643**

▪ *<u>Improvement on the maintenance of the chiller system</u>*

The energy saving from the improvement on the maintenance of the chiller system is estimated over 2 different time periods i.e. during summer and regular semesters with (265 days) and winter season and semester breaks (100 days). The regular operation of chillers would be changed only during the winter and semester breaks when operating the small chiller during the day.

According to the observation and analysis of the efficiency of the chillers from 26th July to 7th August 2006 during the regular semester, the actual performance of the chiller seems to be lower than the manufacturer's specification value. The comparisons between the actual performance and manufacturer's specification of 375-ton and 190-ton chillers at different capacity levels are illustrated in Figures 5.2 and 5.3, respectively. In these figures, the actual performance data were plotted into an average performance curve for ease of visualizing the data.

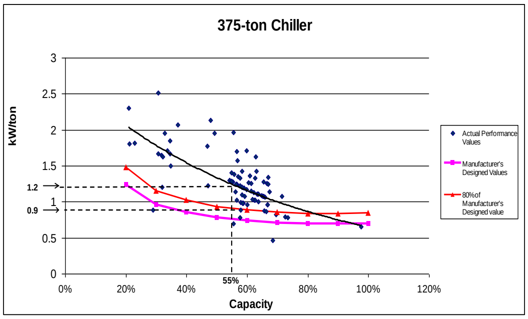

Figure 5.2 Difference between Actual Performance of 375-ton Chiller and 80% of Manufacturer's Designed Value during the Day of Regular and Summer Semesters

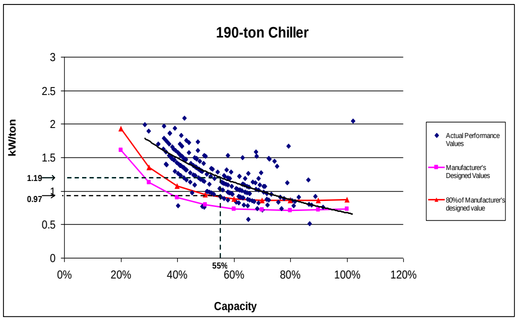

Figure 5.3 Difference between Actual Performance of the 190-ton Chiller and 80% of Manufacturer's Designed Value at Night during Regular and Summer Semesters

The greater difference between the actual performance and manufacturer's specifications value refers to the lower efficiency of the chillers, which often occurs when operating the chiller at a low capacity level. The low efficiency of the chiller in most of its operating capacities indicates that the chiller may have a serious problem and needs immediate service and maintenance. As recommended by York, better main-enance of the chiller should improve the efficiency of the chiller to at least 80% of its manufacturer's specifications. Thus, it is assumed that 80% of manufacturer's designed values could be achieved by maintaining the chiller in good condition. The energy saving due to this improvement of the chiller's efficiency can be determined.

Based on this assumption, the average values of the cooling load demand of the 375 and 190 ton chillers are about 207 and 104 tons or at 55% of both chillers' capacities. The reduction in energy consumption can be calculated at this 55% of the chiller's operating capacity. The difference between kW/ton of the actual performance and 80% of manufacturer's designed value can be determined by projecting the line vertically from 55% of chiller's capacity to the actual performance and 80% of the manufacturer's designed value, and then projecting the line horizontally to the Y-axis. The difference in kW/ton refers to the possible saving on energy consumption by maintenance, which is summarized in Tables 5.3. The energy saving from the improvement on the maintenance of the chiller system during summer and regular semesters with 265 days equals 202,211 kWh or about 659,207 baht annually, including 89,100 and 113,111 kWh of energy saving from 375-ton and 190-ton chillers, respectively.

Table 5.3 Energy Saving from Improvement on the Maintenance of the Chiller System during Summer and Regular Semesters

	Holiday+ Weekend	Office day	Total (hrs)	Actual Perform.	80% of Manu. Designed	Difference	kW	Energy saving per year
					kW/ton			kWh
375-ton operation (hrs)		160						
		1440	1440	1.2	0.9	0.3	61.88	89,100
190-ton operation (hrs)	105	160						
	2520	2400	4920	1.19	0.97	0.22	22.99	113,111
						Total		**202,211**

Based on the proposed operation of the small chiller during the winter season and semester breaks (100 days), it is assumed that the average cooling load demands of the chillers are approximately 71% and 31% of the chiller's capacity during day and night times, respectively. These percentages come from the average values of data collection of cooling load demand during day and night times from the 5th to 9th February 2007. During this period, the small chiller was operated during office hours.

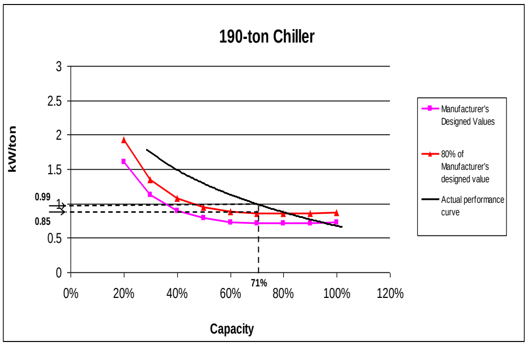

Figure 5.4 Difference between Actual Performance of a 190-ton Chiller and 80% of Manufacturer's Designed Value during the Day of the Winter Season and Semester Breaks

From Figure 5.4, the difference between the actual performance of the chiller at 71% of its capacity and 80% of the manufacturer's designed value is 0.14 kW/ton. The total operation hours are about 900 hours a year. The energy saving from the improvement on the maintenance of the chiller system during the day in the winter and semester breaks is equal to 17,001 kWh annually, which is about 55,423 baht.

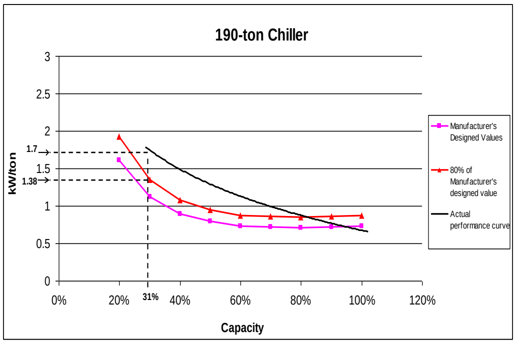

Figure 5.5 Difference between Actual Performance of a 190-ton Chiller and 80% of Manufacturer's Designed Value during the Night of the Winter Season and Semester Breaks

The operation of the chiller at night during the winter and semester breaks is considerably lower than the daytime operation, with 31% of the chiller's operation as illustrated in Figure 5.5. The difference between kW/ton of the actual performance at 31% of the chiller's operation and 80% of manufacturer's designed values of 190-ton chiller is about

0.32 kW/ton. With 1500 operation hours, the energy saving of the small chiller is 28,507 kWh, which is about 92,933 baht.

Table 5.4 Energy Saving from Im-provement on the Maintenance of the Chiller System based on the Proposed Schemes (Operating 190-ton Chiller in Winter Season and Semester Breaks)

	Winter 100 days	**Actual Preform.**	**80% of Manu. Designed**	**Difference**	**Wk**	**Energy saving per year**	**Baht**
			kW/ton			**kWh**	
190-ton (Daytime)	100						
Operation (hrs)	900	0.99	0.85	0.14	18.89	17,001	55,423
190-ton (Nighttime)	100						
Operation (hrs)	1500	1.70	1.38	0.32	19.00	28,507	92,933
					Total	**45,508**	**148,357**

Therefore, energy saving from the improvement on the maintenance of the chiller system during the winter season and semester breaks is equal to 45,508 kWh, which is about 148,357 baht, as sum-marized in Table 5.4.

In conclusion, the total energy saving from the improvement on the maintenance of chiller system is 247,719 kWh or 807,564 baht annually.

5.2 Energy conservation for AHUs & FCUs.

The energy use in this system can be reduced by turning off AHUs and FCUs in some air conditioned spaces with minimal use, resulting in the reduction of the cooling load demand, as well as the energy consumption of the chiller. In this case, the energy saving from turning off AHUc and FCUs can be calculated directly, however, the energy saving from the lower requirement of cooling load demands requires more research and is not considered in this study. The energy conservation scheme for this system is proposed below.

- *Shut down the use of the fourth floor of MHB*

It may be feasible to shut down the 4th floor and relocate the faculty staff to fifth floor offices or other appropriate areas. If the use of the fourth floor is shut off, the cooling load demand of the chiller from MHB will be less, resulting in a reduction in energy consumption. Also, the energy use of AHUs and FCUs can be directly reduced by 11,490 kWh per year. The energy use from the two AHUs is about 8,096 kWhs whereas the energy use of FCUs from classrooms is equal to 3,394 kWh. The utilization of the fourth floor is not economical, when one considers that 16 of 20 faculty offices are left unoccupied. Two AHUs must be operated to serve only 4 faculty offices.

5.3 Energy conservation for chiller pumps

The total energy consumption of the chiller pumps during August 2005 and July 2006 was about 122,510 kWh annually. The annual energy use of chiller pumps for MHB was equal to 41,149 kWh. These VSD chiller pumps were operated according to the load of the chiller. If the load of the chiller is decreased, the load of the chiller pumps will also be reduced, resulting in less energy consumption. Another way to help save the energy of the chiller pumps is to reduce the pump speed and by maintaining its supply through a multiple pump operation. This energy conservation method does not require any new investment for the pump modification, and is selected to be the proposed scheme for this system.

- *Reduce the pump speed and maintain its supply by multiple pump operation*

Reducing the pump speed and maintaining its supply by multiple pump operations was suggested in the special study titled, *An investigation of variable speed chilled water pumps in Shinawatra University [5]*.

According to this special study, there are two practical techniques for reducing the running speed while the secondary pumps are being operated automatically. The first technique called *two pumps parallel operation* is to lower the upper limit of the 1st pump from 90 to 80 percent by running the 2nd pump. Consequently, both pumps will run at reduced speeds of 40-45%. Moreover, the current lower limit for exceeding pump shutdown, which is set at 35 to 40 percent, should be also reduced 30 to 35 percent of the speed.

Another technique is to engage the three pumps in parallel operation during working hours. The request for three pumps in parallel operation can be controlled by appropriate scheduling. Referring to the investigation results of the weekly load pattern, the improvement can be accomplished by cutting the peak load during the working day. The schedule should allow three pumps to run in parallel between peak hours, 8:00 to 17:00 hr, on working days. The average pump speed, which is currently set at 80 - 90 percent, will be reduced to 53 - 60 percent. The new schedule should be applicable by either changing the program algorithm to request the three pumps in parallel operation, or to set up a separate schedule for the third pump to be operated if the average speed of the first two pumps is higher than 80 percent during that time.

The implementation of these two methods will help save energy of 53,012 kWh or 126,369 baht annually. The improvement could be achieved by the two practical techniques mentioned, without any additional investment in hardware.

6. Summary

Table 6.1 Summary of the Energy Cost Saving

		Propose operating pattern	
Systems	**Schemes**	**Energy saving per year (kWh)**	**Energy cost saving per year (baht)**
Air conditioning system			
** Chillers*	• Operate the small chiller and increase the temperature of leaving chilled water during the winter season		
	- Winter season and semester breaks (100 days)	146,300	476,938
	• Operate the small chiller during the regular and summer semesters*	235,641*	768,189*
	• Improve the maintenance of the chiller system		
	- Regular and summer semesters	202,211	659,207
	- Winter season and semester breaks	45,508	148,357
** AHUs and FCUs*	• Shut down the use of forth floor of MHB.	11,490	37,457
** Pumps*	• Reduce the pump speed and maintain its supply by multiple pump operation		
	- Two and three pumps parallel operation during working hour**	53,012**	172,819**
Total		**694,162**	**2,262,967**

Remarks:

* This option does not include the investment cost of split-type air conditioners to be installed at the dormitory buildings.

** The energy saving from reducing the pump speeds and maintaining its supply by multiple pump operation is estimated based on the regular operation of the pumps. So, if the cooling load demand on the chiller is reduced, the operational pattern of the pumps will be changed. The energy saving from the pumps relative to this energy saving scheme may be different.

Implementing all the recommended schemes contributes to 694,162 kWh of energy saving, and the university can save 2.26 million baht a year as shown in Table 6.1. It is noted that Shinawatra University uses a central air conditioning system, which services the MHB, laboratory building, dormitory buildings and sky link. Therefore, the schemes to deal with the air conditioning system need to consider the management of the whole chiller plant.

7. Recommendations and Suggestions for Further Study

- Calibrations of the building automation systems (BAS) and Chiller monitoring programs as well as all the sensors are required to increase the accuracy and reliability of monitoring data.
- In this study, the data from the BAS and chiller monitoring programs were collected manually by the observers. The setting up of automatic data collection on both the BAS and monitoring programs is recommended.
- The thermostat temperature of the FCUs should be set at 25°C to reduce the cooling load demand of the chiller.
- A better method to determine the energy consumption of the pumps that service the MHB is to measure the flow rate at the pipeline branch for the MHB and compare it with the total flow rate.
- One of the recommendations of this study is to sever the dormitory building from the central air conditioning system and install split-type air conditioners in order to operate only the small chiller. Economic and financial analyses, which can be used to assess the feasibility of installing split-type air conditioners, should be carried out in future studies.
- Shutting down the fourth floor decreases the energy consumption of the AHUs and FCUs as well as the chiller system. Further studies should be carried out to determine the energy saving from the chiller system by collecting the data relating to the cooling load demand and energy consumption of the chiller. The temperature on the third, fourth, and fifth floors before and after shutting down the fourth floor should be recorded and analyzed.

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